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Improved Rake Receiver Based On the Signal Sign Separation in Maximal Ratio Combining Technique for Ultra-Wideband Wireless Communication Systems

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Abstract**—**At receiving high data rate in ultra wideband (UWB) technology for many users, there are multiple user interference and inter-symbol interference as obstacles in the multi-path reception technique. Since the rake receivers were designed to collect many resolvable paths, even more than hundred of paths. Rake receiver implementation structures have been proposed towards increasing the complexity for getting better performances in indoor or outdoor multi-path receivers by reducing the bit error rate (BER). So several rake structures were proposed in the past to reduce the number of combining and estimating of resolvable paths. To this aim, we suggested two improved rake receivers based on signal sign separation in the maximal ratio combiner (MRC), called positive-negative MRC selective rake (P-N/MRC-S-rake) and positive-negative MRC partial rake (P-N/MRC-S-rake) receivers. These receivers were introduced to reduce the complexity with less number of fingers and improving the performance with low BER. Before decision circuit, there is a comparator to compare between positive quantity and negative quantity to decide whether the transmitted bit is 1 or 0. The BER was driven by MATLAB simulation with multi-path environments for impulse radio time-hopping binary phase shift keying (TH-BPSK) modulation and the results were compared with those of conventional rake receivers.

Keywords**—**Selective and partial rake receivers, positive and negative signal separation, maximal ratio combiner, bit error rate performance.

I. INTRODUCTION

RAKE processing of ultra wideband (UWB) signals through indoor and outdoor multi-path propagation has an ability to collect the energy of multi-path diversity copies. So that, rake receiver is important device to increase the reception gain and to improve the UWB systems performance. In the attendance of inter-symbol interference (ISI) during symbol transmission, maximal ratio combining rake receiver (MRC-RR) can be used to maximize the signal to noise ratio (SNR) [1]. ISI is a serious obstacle, so it needs to be suppressed specially at high speed data transmission. Suppressing or reducing ISI is the important area of research in the rake receiver with capability of a good effect. Since the bandwidth of UWB is 7.5 GHz according to Federal communications commission (FCC) [2], multi-path components (MPCs) can be resolved to give ability in the rake receiver to extract the individual multipath signals. There are three diversity combining schemes to combine the resolved paths. The optimal one is the all rake (A-rake) receiver which combines all MPCs, so it is more complex in application with more fingers should be used. Selective rake (S-rake) combines the selected strong paths (L_s) from several clusters. Partial rake (P-rake) receiver is used to combine only the first L_p paths arriving at limited duration out of the resolved MPCs [3]. The goal of this research is to decrease probability error of bit, reduce the system cost, minimize the number of correlators, and small in size.

II. TRANSMISSION AND MULTI-PATH CHANNEL MODEL

The main spread-spectrum techniques in UWB communications are called direct-sequence UWB (DS-UWB) and time-hopping UWB (TH-UWB). In this paper we considered time-hopping spread-spectrum technique used in UWB systems of very short pulses {p(t)} and pulse width of T_p as shown in Fig. 1 which depicts a sequence of second order Gaussian pulses of low duty cycle with frame structure of $T_f >> T_p$ length each along the symbol period (T_s). The data bits are repeatedly transmitted over several frames (N_s) and each frame is divided in to four chip slots of T_c duration and one slot carries user's transmitted pulse. For analysis purpose, the energy of signaling pulse p (t) was considered to be unity, i.e., $\int_{-\infty}^{\infty} p^2(t)dt = 1$ and the symbol duration $T_s = (N_s-1)T_f$. The frame duration (T_f) is much greater than the chip duration (T_c) and pulse duration (T_p) to avoid the collisions or interferences [4].

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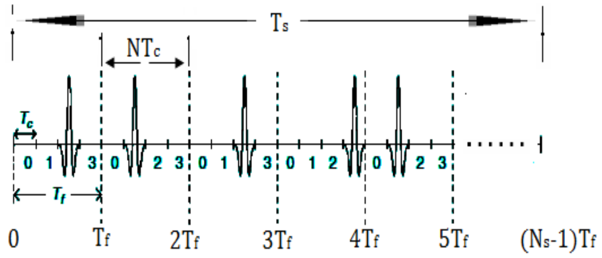

Fig. 1 TH-UWB signal

We assume a binary phase shift keying BPSK modulation approach in the transmission system. In BPSK, the positive polarity represents bit 1and negative polarity represents bit 0. The advantage of using BPSK scheme is removing the discrete spectral lines in the power spectral density (PSD) and produces zero mean at changing the polarity [5]. The information can be generated randomly by binary source that is to be transmitted at a symbol rate of $1/T_s$ bits/sec. The transmitted pulse shaping form is $P_T(t)$ of duration T_p is equal to 0.167 ns and pulse energy E_p is considered as a second derivative of a Gaussian function $e^{-2\pi(t/\tau)^2}$ and second derivative is

$$P_T(t)=[1-4\pi(t/\tau)^2]e^{-2\pi(t/\tau)^2}, \tag{1}$$

where, τ is the shape factor or time scaling factor.

Transmitted signal is:

$$S(t)=\sum_{j=-\infty}^{\infty} C_j P_T(t-jT_c), \tag{2}$$

where $C_j = x_m \cdot w_n$ …..- $\infty < m < \infty$, $n=0, 1, 2, \ldots N_c-1$

The TH-BPSK-UWB transmitted signal format for different users can be modeled as:

$$S^u(t)=\sqrt{E^u{}_p}\sum_{m=-\infty}^{\infty} x^u{}_m \sum_{n=0}^{N_c-1} w_n P_T(t-mT_s-n^uT_c-\tau^u{}_0), \tag{3}$$

where $S^u(t)$ is user (u) transmitted signal, $\tau^u{}_o$ is reference delay for the first user which caused asynchronous transmission ($0 \le \tau^u{}_o \le T_f$), and $n^u \epsilon [0, 1, \ldots N_c-1]$ is used to assign the users up to the number of chips (N_c-1).

The S (t) signal passes through a multipath channel and the channel model should be based on a modified Saleh-Valenzuela (S-V) channel model for indoor multipath propagation [6]. It is proposed by IEEE 802.15 that based on this clustering phenomenon observed in several channel measurements, we propose an UWB channel model derived from the Saleh-Valenzuela model with a couple of slight modifications. We recommend using a lognormal distribution rather than a Rayleigh distribution for the multipath gain magnitude, since our observations show that the lognormal distribution seems to better fit the measurement data. In addition, independent fading is assumed for each cluster as well as each ray within the cluster. Therefore, the multipath model consists of the following, discrete time impulse response [7]:

$$h_i(t)=X_i\sum_{l=0}^{L}\sum_{k=0}^{K}\alpha^i_{k,l}\exp^{j\theta_{k,l}}\delta(t-T^i_l-\tau^i_{k,l}), \tag{4}$$

where $\alpha^i_{k,l}$ are the multipath gain coefficients of the k^{th} ray within l^{th} cluster, T^i_l is the delay of the l^{th} cluster, $\tau^i_{k,l}$ is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time (T^i_l), X_i represents the log-normal random variable which represent shadowing, L is the number of observed clusters , $\theta_{k,l}$ is uniformly distributed phase in the range of $[0, 2\pi]$, and i refers to the i^{th} realization of the channel model (CM). CM3 model is based on NLOS (4-10) channel measurements reported in [2] with seven model parameters are: Λ (1/ns) is cluster arrival rate of 0.0667, λ (1/ns) is ray arrival rate of 2.1, i.e., the arrival rate of path within each cluster, Γ (ns) is the cluster decay factor of 14, γ (ns) is the ray decay factor of 7.9, σ_1 (dB) is standard deviation of cluster lognormal fading term of 3.3941, σ_2 (dB) is standard deviation of ray lognormal fading term of 3.3941, and σ_x (dB) is standard deviation of lognormal shadowing term for total multipath realization of 3.

The transmitted signal is convoluted with channel impulse response of the multi-path channel and the output of the UWB channel model is added with n (t) additive white Gaussian noise (AWGN) of power spectral density $N_0/2$ [8]. So the received signal model r(t) can be formulated to get the general received signal expression from user (u).

$$r(t)=X_i\sqrt{E^u{}_p}\sum_{m=-\infty}^{\infty}x^u{}_m\sum_{l=0}^{L}\sum_{k=0}^{K}\sum_{n=0}^{N_c-1}\alpha^i_{l,k}w_nP_T(t-mT_s-n^uT_c-\tau^u{}_{k,l})+n(t) \tag{5}$$

III. THE PROPOSED RAKE RECEIVER

After corrupting by a white Gaussian noise n(t), the UWB signal r (t) is received by receiver of F copy fingers. The signal is multiplied by generated template signal (G_{af}) which is same as the transmitted waveform and passes through integrator for correlation process with the required signal [9]. Each finger behaves as a matched filter to maximize the ability for suppressing most of the noise as much as possible [10]. As shown in Fig. 2, the output of the finger is decomposed in to r_o (t) and n_o (t) due to the input signal and input noise respectively.

$$r_0(t)=\int_0^t r(t)G_{af}(t-\tau)d\tau \tag{6}$$

$$n_0(t) = \int_0^t n(t) G_{af}(t-\tau) d\tau \qquad (7)$$

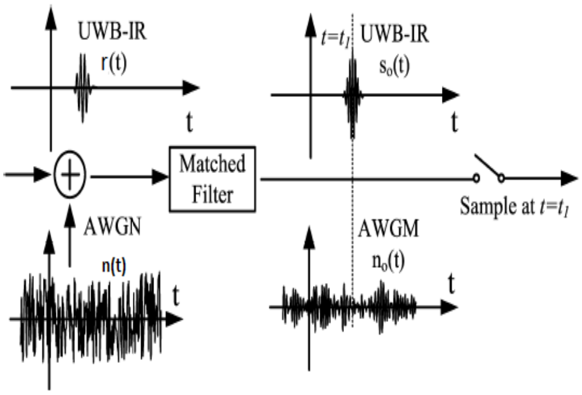

Fig. 2 Time domain scenario to improve the SNR

The finger output signal ($r_s(t) = r_o(t) + n_o(t)$) is multiplied by assuming receiver tap weights vector ($\beta_{a0}, \beta_{a1}, \ldots\ldots \beta_{a(F-1)}$) and sampled according to Niquist sampling theorem with high sampling rate. The technique that leads to least BER is MRC after correcting the phase rotation that caused by a fading channels and summing the chips of the current symbols. As shown in Fig. 3, the received signal by MRC is a sum of the desired signal and noise so that the structure of proposed rake receiver contains P-N/MRC combiner for collecting separately the positive quantities (A) and negative quantities (B) of multi-path energy. The quantities are defined by Q_s with P is the number of positive values and N is the number of negative values in the summation expressions in the MRC combiner and the positive and negative quantities are expressed as:

$$A = \sum_{P} Q_s(t-\tau) \qquad (8)$$

$$B = \sum_{N} Q_s(t-\tau) \qquad (9)$$

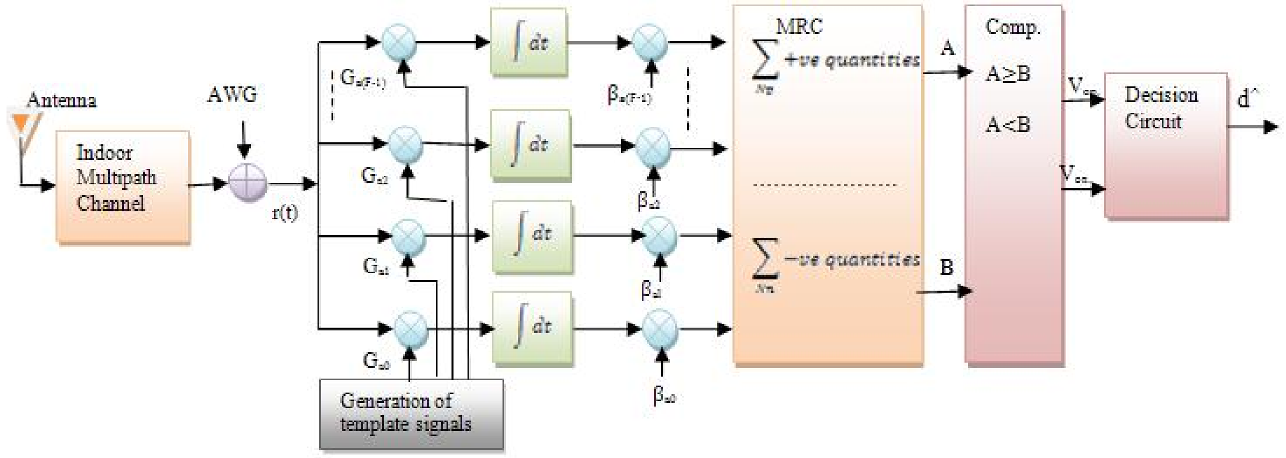

Fig. 3 Block diagram of the proposed P-N/MRC rake receiver

IV. SIMULATION RESULTS AND DISCUSSION

The analysis and simulated results are based on indoor non Line-of-sight (NLOS) channels (CM3) with range of ten meters and the channel model parameters were taken from [2]. Selective rake (S-rake) and partial rake (P-rake) were simulated using MATLAB software to determine the advantage of capturing the strongest paths and the first arriving paths respectively within four fingers. The transmitted bits were generated randomly and assumed to be 50 bits. The shaping factor for the pulse is 0.22 ns with $N_s = 5$ pulses per bit and the transmitted bits were modulated using BPSK modulation. Several simulations were carried out to represent the bit error rate after averaging the values over 50 channels and the SNR was varied from 0 to 20 to confirm the performance of the proposed rake receiver. The performance evaluation of the proposed S-rake receiver is illustrated in Fig. 4 for four users and eight fingers compared with conventional rake receiver (C-rake). When the SNR is 10dB under CM3 channel condition, the BER is decreased from 0.17 with C-rake to 0.06 with the proposed S-rake design. Fig. 5 shows the interesting results for BER when using four fingers and two users in comparison with the C-rake and the BER decreasing from 0.15 to 0.0015 at SNR of 10dB. The complexity proposed P-rake receiver performances are illustrated in Fig. 6 when combines the first eight arriving paths with four users and Fig. 7 when combines the first four arriving paths with two users. These quantities are passed to the comparator to decide if A ≥ B, comparator output voltage is V_{op} and the estimated message bit ($\hat{d}$) is 1, when A < B, comparator output is V_{on} and the estimated message bit is 0 as in Table I.

TABLE I
COMPARATOR OUTPUT

Comparator output	V_{op}	V_{on}
A≥B	1	0
A<B	0	1

To compare these results with those of C-rake receiver, at SNR = 10dB, BER is reduced from 0.12 to 0.09 as in Fig. 6 while BER is reduced from 0.11 to 0.0015 as in Fig. 7. The TH-UWB system performance for both S-rake and P-rake receivers was reduced with increasing the number of users because of user interference are presented and can be improved when collecting energy from several rake fingers.

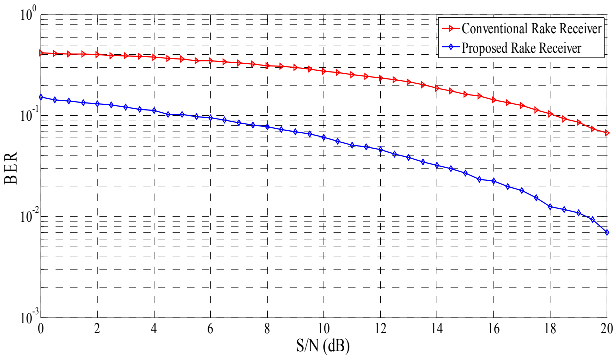

Fig. 4 The BER performance against SNR of selective rake receiver at L_s=8 and four users during CM3

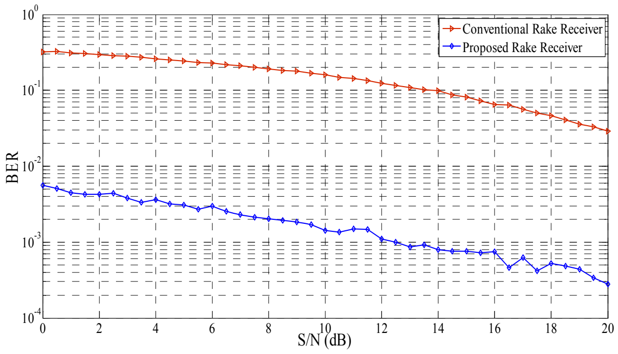

Fig. 5 The BER performance against SNR of selective rake receiver at L_s=4 and two users during CM3

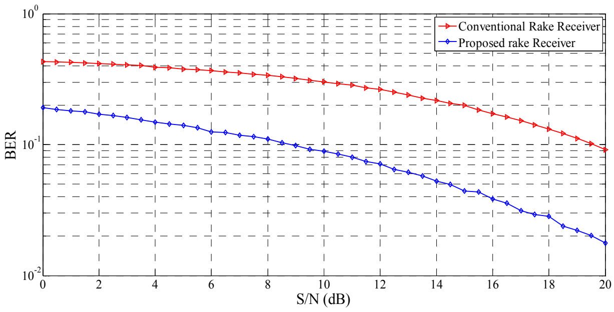

Fig. 6 The BER performance against SNR of partial rake receiver at L_p=8 and four users during CM3

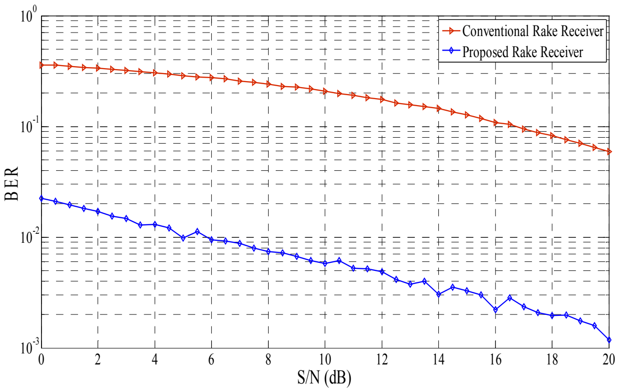

Fig. 7 The BER performance against SNR of partial rake receiver at L_p=4 and two users during CM3

V. CONCLUSIONS

In this paper, the sign separation P-N/MRC rake receiver based on MRC combining technique for TH-UWB system was presented. The two proposed rake receivers for UWB applications, called P-N/S-rake and P-N/P-rake, were analyzed and simulated using MATLAB software to display the system performance by reducing the BER. The suggested receivers were compared with the conventional rake receiver and they achieve better evaluated performances without increasing the receiver complexity under CM3 channel model.

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